

CLASSICAL PHYSICS CONCEPTS EXPLAINED

UNDERSTANDING THE PILLARS OF THE UNIVERSE: CLASSICAL PHYSICS CONCEPTS EXPLAINED

CLASSICAL PHYSICS CONCEPTS EXPLAINED IN THIS COMPREHENSIVE GUIDE PROVIDE THE FOUNDATIONAL BEDROCK UPON WHICH MUCH OF OUR UNDERSTANDING OF THE PHYSICAL WORLD IS BUILT. FROM THE PREDICTABLE DANCE OF CELESTIAL BODIES TO THE EVERYDAY MECHANICS OF MOTION AND ENERGY, THESE PRINCIPLES GOVERN THE MACROSCOPIC UNIVERSE WE EXPERIENCE. THIS ARTICLE DELVES INTO THE ESSENTIAL IDEAS OF CLASSICAL MECHANICS, THERMODYNAMICS, ELECTROMAGNETISM, AND OPTICS, DEMYSTIFYING COMPLEX THEORIES WITH CLEAR, DETAILED EXPLANATIONS. WE WILL EXPLORE THE LAWS THAT DESCRIBE HOW OBJECTS MOVE, HOW HEAT AND ENERGY INTERACT, THE FUNDAMENTAL FORCES OF ELECTRICITY AND MAGNETISM, AND THE NATURE OF LIGHT ITSELF. BY BREAKING DOWN THESE CORE CONCEPTS, WE AIM TO ILLUMINATE THE ELEGANCE AND POWER OF CLASSICAL PHYSICS.

TABLE OF CONTENTS

INTRODUCTION TO CLASSICAL PHYSICS

NEWTONIAN MECHANICS: THE LAWS OF MOTION

WORK, ENERGY, AND POWER

THERMODYNAMICS: THE STUDY OF HEAT AND ENERGY

ELECTROMAGNETISM: THE UNIFICATION OF FORCES

OPTICS: THE SCIENCE OF LIGHT

THE ENDURING LEGACY OF CLASSICAL PHYSICS

NEWTONIAN MECHANICS: THE LAWS OF MOTION

NEWTONIAN MECHANICS, OFTEN REFERRED TO AS CLASSICAL MECHANICS, FORMS THE CORNERSTONE OF OUR UNDERSTANDING OF HOW OBJECTS BEHAVE IN RESPONSE TO FORCES. DEVELOPED BY SIR ISAAC NEWTON IN HIS SEMINAL WORK "PRINCIPIA MATHEMATICA," THESE LAWS PROVIDE A POWERFUL FRAMEWORK FOR ANALYZING EVERYTHING FROM THE FALL OF AN APPLE TO THE ORBITS OF PLANETS. THEY ARE BASED ON THE CONCEPT OF INERTIA, FORCE, AND MOMENTUM, AND THEIR ELEGANT SIMPLICITY BELIES THEIR PROFOUND PREDICTIVE POWER IN THE MACROSCOPIC WORLD.

NEWTON'S FIRST LAW OF MOTION: THE LAW OF INERTIA

NEWTON'S FIRST LAW, ALSO KNOWN AS THE LAW OF INERTIA, STATES THAT AN OBJECT AT REST WILL STAY AT REST, AND AN OBJECT IN MOTION WILL STAY IN MOTION WITH THE SAME SPEED AND IN THE SAME DIRECTION UNLESS ACTED UPON BY AN UNBALANCED FORCE. INERTIA IS THE INHERENT RESISTANCE OF ANY PHYSICAL OBJECT TO ANY CHANGE IN ITS STATE OF MOTION. THIS MEANS THAT IF AN OBJECT IS MOVING, IT WILL CONTINUE TO MOVE AT A CONSTANT VELOCITY (SPEED AND DIRECTION) UNLESS SOMETHING PUSHES OR PULLS ON IT. CONVERSELY, IF AN OBJECT IS STATIONARY, IT WILL REMAIN STATIONARY UNTIL A FORCE CAUSES IT TO MOVE. WITHOUT FRICTION OR AIR RESISTANCE, A BALL KICKED ON A PERFECTLY SMOOTH, INFINITE PLANE WOULD CONTINUE ROLLING FOREVER.

NEWTON'S SECOND LAW OF MOTION: FORCE, MASS, AND ACCELERATION

THE SECOND LAW OF MOTION IS PERHAPS THE MOST MATHEMATICALLY RICH OF THE THREE, STATING THAT THE ACCELERATION OF AN OBJECT IS DIRECTLY PROPORTIONAL TO THE NET FORCE ACTING ON IT AND INVERSELY PROPORTIONAL TO ITS MASS. MATHEMATICALLY, THIS IS EXPRESSED BY THE ICONIC FORMULA: $F = ma$, WHERE F REPRESENTS THE NET FORCE, m IS THE MASS OF THE OBJECT, AND a IS ITS ACCELERATION. THIS LAW QUANTIFIES THE RELATIONSHIP BETWEEN FORCE AND MOTION. A LARGER FORCE WILL PRODUCE A GREATER ACCELERATION FOR A GIVEN MASS, WHILE A MORE MASSIVE OBJECT WILL EXPERIENCE LESS ACCELERATION UNDER THE SAME APPLIED FORCE. UNDERSTANDING THIS LAW IS CRUCIAL FOR CALCULATING TRAJECTORIES, PREDICTING HOW OBJECTS WILL RESPOND TO IMPACTS, AND DESIGNING ANY SYSTEM INVOLVING MOTION.

NEWTON'S THIRD LAW OF MOTION: ACTION AND REACTION

NEWTON'S THIRD LAW OF MOTION ASSERTS THAT FOR EVERY ACTION, THERE IS AN EQUAL AND OPPOSITE REACTION. THIS FUNDAMENTAL PRINCIPLE IMPLIES THAT FORCES ALWAYS OCCUR IN PAIRS. WHEN ONE OBJECT EXERTS A FORCE ON A SECOND OBJECT, THE SECOND OBJECT SIMULTANEOUSLY EXERTS A FORCE EQUAL IN MAGNITUDE AND OPPOSITE IN DIRECTION ON THE FIRST OBJECT. FOR EXAMPLE, WHEN YOU PUSH AGAINST A WALL, THE WALL PUSHES BACK ON YOU WITH AN EQUAL FORCE. SIMILARLY, A ROCKET EXPELS HOT GAS DOWNWARDS (ACTION), AND THE EXPELLED GAS PUSHES THE ROCKET UPWARDS (REACTION), ENABLING FLIGHT. THIS RECIPROCAL NATURE OF FORCES IS ESSENTIAL FOR UNDERSTANDING INTERACTIONS BETWEEN OBJECTS.

WORK, ENERGY, AND POWER

WORK, ENERGY, AND POWER ARE INTERCONNECTED CONCEPTS THAT QUANTIFY THE TRANSFER AND TRANSFORMATION OF MOTION AND CAPABILITY WITHIN PHYSICAL SYSTEMS. THEY ARE CENTRAL TO UNDERSTANDING HOW FORCES CAUSE CHANGES AND HOW EFFICIENTLY THOSE CHANGES CAN BE ACHIEVED. THESE CONCEPTS ARE FUNDAMENTAL NOT ONLY IN MECHANICS BUT ALSO IN MANY OTHER BRANCHES OF PHYSICS AND ENGINEERING.

DEFINING WORK IN PHYSICS

IN PHYSICS, WORK IS DONE WHEN A FORCE CAUSES AN OBJECT TO MOVE A CERTAIN DISTANCE. IT IS NOT SIMPLY THE APPLICATION OF A FORCE; THERE MUST BE DISPLACEMENT. THE FORMULA FOR WORK (W) IS GIVEN BY $W = Fd \cos(\theta)$, WHERE F IS THE MAGNITUDE OF THE FORCE, d IS THE MAGNITUDE OF THE DISPLACEMENT, AND θ IS THE ANGLE BETWEEN THE FORCE AND THE DISPLACEMENT VECTORS. IF THE FORCE AND DISPLACEMENT ARE IN THE SAME DIRECTION, WORK IS POSITIVE. IF THEY ARE IN OPPOSITE DIRECTIONS, WORK IS NEGATIVE, MEANING THE FORCE OPPOSES THE MOTION. IF THE FORCE IS PERPENDICULAR TO THE DISPLACEMENT, NO WORK IS DONE, SUCH AS CARRYING A HEAVY BOX HORIZONTALLY AT A CONSTANT SPEED; YOUR UPWARD LIFTING FORCE DOES NO WORK BECAUSE THE DISPLACEMENT IS HORIZONTAL.

UNDERSTANDING ENERGY: THE CAPACITY TO DO WORK

ENERGY IS THE CAPACITY OF A PHYSICAL SYSTEM TO PERFORM WORK. IT EXISTS IN VARIOUS FORMS, INCLUDING KINETIC ENERGY (ENERGY OF MOTION), POTENTIAL ENERGY (STORED ENERGY DUE TO POSITION OR CONFIGURATION), THERMAL ENERGY, CHEMICAL ENERGY, AND NUCLEAR ENERGY. THE LAW OF CONSERVATION OF ENERGY, A CORNERSTONE OF PHYSICS, STATES THAT ENERGY CANNOT BE CREATED OR DESTROYED, ONLY TRANSFERRED OR TRANSFORMED FROM ONE FORM TO ANOTHER. FOR INSTANCE, WHEN YOU LIFT A BALL, YOU DO WORK, INCREASING ITS POTENTIAL ENERGY. WHEN YOU DROP IT, THIS POTENTIAL ENERGY IS CONVERTED INTO KINETIC ENERGY AS IT FALLS.

THE CONCEPT OF POWER

POWER IS THE RATE AT WHICH WORK IS DONE OR ENERGY IS TRANSFERRED. IT TELLS US HOW QUICKLY ENERGY IS BEING USED OR HOW FAST WORK IS BEING PERFORMED. THE FORMULA FOR AVERAGE POWER (P) IS $P = W/T$, WHERE W IS THE WORK DONE AND T IS THE TIME TAKEN. THE STANDARD UNIT OF POWER IS THE WATT (W), WHICH IS EQUIVALENT TO ONE JOULE PER SECOND. A POWERFUL ENGINE CAN DO A LARGE AMOUNT OF WORK IN A SHORT PERIOD, WHILE A LESS POWERFUL ONE WOULD TAKE LONGER TO ACHIEVE THE SAME RESULT. THIS METRIC IS CRUCIAL IN EVALUATING THE EFFICIENCY AND CAPABILITY OF MACHINES AND SYSTEMS.

THERMODYNAMICS: THE STUDY OF HEAT AND ENERGY

THERMODYNAMICS IS THE BRANCH OF PHYSICS THAT DEALS WITH HEAT, WORK, TEMPERATURE, AND ENERGY, AND THEIR INTERRELATIONSHIPS. IT GOVERNS HOW ENERGY IS TRANSFERRED AND TRANSFORMED, PARTICULARLY IN SYSTEMS INVOLVING

MACROSCOPIC QUANTITIES. THE LAWS OF THERMODYNAMICS ARE FUNDAMENTAL TO UNDERSTANDING ENGINES, REFRIGERATORS, AND THE FUNDAMENTAL LIMITATIONS ON ENERGY CONVERSION.

THE LAWS OF THERMODYNAMICS

THERE ARE FOUR FUNDAMENTAL LAWS OF THERMODYNAMICS:

- **ZEROth LAW:** IF TWO SYSTEMS ARE EACH IN THERMAL EQUILIBRIUM WITH A THIRD SYSTEM, THEN THEY ARE IN THERMAL EQUILIBRIUM WITH EACH OTHER. THIS LAW ESTABLISHES THE CONCEPT OF TEMPERATURE AS A FUNDAMENTAL PROPERTY.
- **FIRST LAW:** THIS IS THE LAW OF CONSERVATION OF ENERGY APPLIED TO THERMODYNAMIC SYSTEMS. IT STATES THAT THE CHANGE IN INTERNAL ENERGY OF A SYSTEM IS EQUAL TO THE HEAT ADDED TO THE SYSTEM MINUS THE WORK DONE BY THE SYSTEM.
- **SECOND LAW:** THIS LAW INTRODUCES THE CONCEPT OF ENTROPY AND STATES THAT THE TOTAL ENTROPY OF AN ISOLATED SYSTEM CAN ONLY INCREASE OVER TIME, OR REMAIN CONSTANT IN IDEAL CASES WHERE THE SYSTEM IS IN A STEADY STATE OR UNDERGOING A REVERSIBLE PROCESS. IT IMPLIES THAT HEAT NATURALLY FLOWS FROM HOTTER TO COLDER OBJECTS AND THAT NO PROCESS IS 100% EFFICIENT IN CONVERTING HEAT INTO WORK.
- **THIRD LAW:** THIS LAW STATES THAT AS THE TEMPERATURE OF A SYSTEM APPROACHES ABSOLUTE ZERO, ITS ENTROPY APPROACHES A MINIMUM OR ZERO VALUE. IT SUGGESTS THAT ABSOLUTE ZERO IS UNATTAINABLE.

HEAT TRANSFER MECHANISMS

HEAT CAN BE TRANSFERRED THROUGH THREE PRIMARY MECHANISMS:

- **CONDUCTION:** THE TRANSFER OF HEAT THROUGH DIRECT CONTACT BETWEEN PARTICLES. THIS IS COMMON IN SOLIDS.
- **CONVECTION:** THE TRANSFER OF HEAT THROUGH THE MOVEMENT OF FLUIDS (LIQUIDS OR GASES). WARMER, LESS DENSE FLUID RISES, WHILE COOLER, DENSER FLUID SINKS, CREATING CURRENTS.
- **RADIATION:** THE TRANSFER OF HEAT THROUGH ELECTROMAGNETIC WAVES. THIS IS HOW THE SUN WARMS THE EARTH, AND IT DOES NOT REQUIRE A MEDIUM.

ELECTROMAGNETISM: THE UNIFICATION OF FORCES

ELECTROMAGNETISM IS A FUNDAMENTAL FORCE OF NATURE THAT DESCRIBES THE INTERACTIONS BETWEEN ELECTRICALLY CHARGED PARTICLES. IT ENCOMPASSES BOTH ELECTRICITY AND MAGNETISM, WHICH WERE FAMOUSLY UNIFIED BY JAMES CLERK MAXWELL. THIS FIELD IS CRUCIAL FOR UNDERSTANDING EVERYTHING FROM THE FLOW OF CURRENT IN WIRES TO THE PROPAGATION OF LIGHT AND THE BEHAVIOR OF SUBATOMIC PARTICLES.

ELECTRIC FIELDS AND CHARGES

ELECTRIC CHARGE IS A FUNDAMENTAL PROPERTY OF MATTER THAT CAUSES IT TO EXPERIENCE A FORCE WHEN PLACED IN AN ELECTRIC FIELD. THERE ARE TWO TYPES OF ELECTRIC CHARGE: POSITIVE AND NEGATIVE. LIKE CHARGES REPEL EACH OTHER, WHILE OPPOSITE CHARGES ATTRACT. AN ELECTRIC FIELD IS A REGION OF SPACE AROUND AN ELECTRIC CHARGE WHERE ANOTHER CHARGED OBJECT WOULD EXPERIENCE A FORCE. THE STRENGTH AND DIRECTION OF THE ELECTRIC FIELD ARE DETERMINED BY THE SOURCE CHARGE AND THE DISTANCE FROM IT.

MAGNETIC FIELDS AND THEIR SOURCES

MAGNETIC FIELDS ARE REGIONS OF SPACE WHERE MAGNETIC FORCES CAN BE DETECTED. THEY ARE PRODUCED BY MOVING ELECTRIC CHARGES (ELECTRIC CURRENTS) AND BY THE INTRINSIC MAGNETIC MOMENTS OF ELEMENTARY PARTICLES, SUCH AS ELECTRONS. MAGNETS HAVE POLES, TYPICALLY DESIGNATED AS NORTH AND SOUTH. LIKE POLES REPEL, AND OPPOSITE POLES ATTRACT. A MAGNETIC FIELD EXERTS A FORCE ON MOVING ELECTRIC CHARGES AND ON MAGNETIC MATERIALS.

MAXWELL'S EQUATIONS AND ELECTROMAGNETIC WAVES

JAMES CLERK MAXWELL'S GROUNDBREAKING WORK SYNTHESIZED ELECTRICITY AND MAGNETISM INTO A SINGLE COHERENT THEORY DESCRIBED BY A SET OF FOUR EQUATIONS, NOW KNOWN AS MAXWELL'S EQUATIONS. THESE EQUATIONS ELEGANTLY PREDICT THE EXISTENCE OF ELECTROMAGNETIC WAVES – OSCILLATING ELECTRIC AND MAGNETIC FIELDS THAT PROPAGATE THROUGH SPACE AT THE SPEED OF LIGHT. LIGHT ITSELF IS A FORM OF ELECTROMAGNETIC RADIATION, AND THIS DISCOVERY REVOLUTIONIZED OUR UNDERSTANDING OF THE UNIVERSE AND LED TO TECHNOLOGIES LIKE RADIO, TELEVISION, AND WIRELESS COMMUNICATION.

OPTICS: THE SCIENCE OF LIGHT

OPTICS IS THE BRANCH OF PHYSICS THAT STUDIES THE BEHAVIOR AND PROPERTIES OF LIGHT, INCLUDING ITS INTERACTIONS WITH MATTER AND THE CONSTRUCTION OF INSTRUMENTS THAT USE OR DETECT LIGHT. CLASSICAL OPTICS IS PRIMARILY CONCERNED WITH GEOMETRICAL OPTICS AND WAVE OPTICS.

GEOMETRICAL OPTICS: REFLECTION AND REFRACTION

GEOMETRICAL OPTICS TREATS LIGHT AS RAYS AND DESCRIBES ITS BEHAVIOR USING PRINCIPLES OF REFLECTION AND REFRACTION. REFLECTION OCCURS WHEN LIGHT BOUNCES OFF A SURFACE, FOLLOWING THE LAW OF REFLECTION: THE ANGLE OF INCIDENCE EQUALS THE ANGLE OF REFLECTION. REFRACTION IS THE BENDING OF LIGHT AS IT PASSES FROM ONE MEDIUM TO ANOTHER DUE TO A CHANGE IN SPEED. THIS PHENOMENON EXPLAINS WHY A STRAW APPEARS BENT IN A GLASS OF WATER AND IS THE PRINCIPLE BEHIND LENSES IN EYEGASSES AND TELESCOPES.

WAVE OPTICS: INTERFERENCE AND DIFFRACTION

WAVE OPTICS, ON THE OTHER HAND, TREATS LIGHT AS A WAVE. PHENOMENA LIKE INTERFERENCE AND DIFFRACTION CANNOT BE EXPLAINED BY THE RAY MODEL. INTERFERENCE OCCURS WHEN TWO OR MORE WAVES OVERLAP, RESULTING IN A NEW WAVE WHOSE AMPLITUDE IS THE SUM OF THE AMPLITUDES OF THE INDIVIDUAL WAVES. THIS CAN LEAD TO CONSTRUCTIVE INTERFERENCE (BRIGHTER LIGHT) OR DESTRUCTIVE INTERFERENCE (DIMMER LIGHT). DIFFRACTION IS THE BENDING OF WAVES AROUND OBSTACLES OR THROUGH NARROW OPENINGS. BOTH INTERFERENCE AND DIFFRACTION PROVIDE STRONG EVIDENCE FOR THE WAVE NATURE OF LIGHT.

THE ENDURING LEGACY OF CLASSICAL PHYSICS

WHILE MODERN PHYSICS, INCLUDING QUANTUM MECHANICS AND RELATIVITY, HAS EXPANDED OUR UNDERSTANDING TO THE SUBATOMIC AND COSMIC SCALES, THE PRINCIPLES OF CLASSICAL PHYSICS REMAIN REMARKABLY RELEVANT AND INDISPENSABLE. THEY ACCURATELY DESCRIBE THE VAST MAJORITY OF PHENOMENA WE ENCOUNTER IN OUR DAILY LIVES AND ARE THE BEDROCK OF COUNTLESS ENGINEERING DISCIPLINES, FROM CIVIL AND MECHANICAL TO ELECTRICAL AND AERONAUTICAL. THE ELEGANT LAWS OF MOTION, THE CONSERVATION OF ENERGY, THE FUNDAMENTAL FORCES OF ELECTROMAGNETISM, AND THE BEHAVIOR OF LIGHT CONTINUE TO FORM THE CONCEPTUAL FRAMEWORK FOR MUCH OF OUR SCIENTIFIC AND TECHNOLOGICAL PROGRESS. UNDERSTANDING THESE CLASSICAL CONCEPTS IS NOT MERELY AN ACADEMIC EXERCISE; IT IS AN ESSENTIAL STEP TOWARDS APPRECIATING THE INTRICATE WORKINGS OF THE UNIVERSE AND HARNESSING ITS POWER.

FAQ

Q: WHAT ARE THE PRIMARY BRANCHES OF CLASSICAL PHYSICS?

A: THE PRIMARY BRANCHES OF CLASSICAL PHYSICS TYPICALLY INCLUDE NEWTONIAN MECHANICS (DESCRIBING MOTION AND FORCES), THERMODYNAMICS (DEALING WITH HEAT AND ENERGY), ELECTROMAGNETISM (GOVERNING ELECTRIC AND MAGNETIC PHENOMENA), AND OPTICS (THE STUDY OF LIGHT).

Q: WHY IS CLASSICAL PHYSICS STILL IMPORTANT IF WE HAVE QUANTUM MECHANICS?

A: CLASSICAL PHYSICS PROVIDES A HIGHLY ACCURATE AND INTUITIVE DESCRIPTION OF MACROSCOPIC PHENOMENA, WHICH ARE MOST OF WHAT WE EXPERIENCE. IT IS THE FOUNDATION FOR ENGINEERING AND TECHNOLOGY AND IS SUFFICIENT FOR MOST PRACTICAL APPLICATIONS. QUANTUM MECHANICS IS NECESSARY FOR DESCRIBING THE BEHAVIOR OF MATTER AND ENERGY AT ATOMIC AND SUBATOMIC SCALES.

Q: CAN YOU GIVE A SIMPLE EXAMPLE OF NEWTON'S FIRST LAW IN ACTION?

A: WHEN A CAR IS MOVING AT A CONSTANT SPEED, IT WILL CONTINUE TO MOVE AT THAT SPEED UNLESS THE DRIVER APPLIES THE BRAKES (APPLYING A FORCE TO SLOW IT DOWN) OR AN EXTERNAL FORCE LIKE FRICTION FROM THE ROAD ACTS UPON IT. SIMILARLY, A BALL RESTING ON A TABLE WILL REMAIN AT REST UNTIL SOMEONE PUSHES IT.

Q: WHAT IS THE DIFFERENCE BETWEEN ENERGY AND POWER?

A: ENERGY IS THE CAPACITY TO DO WORK, MEASURED IN JOULES. POWER IS THE RATE AT WHICH WORK IS DONE OR ENERGY IS TRANSFERRED, MEASURED IN WATTS (JOULES PER SECOND). THINK OF IT AS ENERGY BEING THE AMOUNT OF FUEL, AND POWER BEING HOW QUICKLY YOU CAN BURN THAT FUEL.

Q: HOW DO MAXWELL'S EQUATIONS UNIFY ELECTRICITY AND MAGNETISM?

A: MAXWELL'S EQUATIONS SHOW THAT CHANGING ELECTRIC FIELDS CREATE MAGNETIC FIELDS, AND CHANGING MAGNETIC FIELDS CREATE ELECTRIC FIELDS. THIS INTERCONNECTEDNESS MEANS THAT ELECTRICITY AND MAGNETISM ARE NOT SEPARATE PHENOMENA BUT RATHER TWO ASPECTS OF A SINGLE ELECTROMAGNETIC FORCE, AND THEY PREDICT THE EXISTENCE OF ELECTROMAGNETIC WAVES TRAVELING AT THE SPEED OF LIGHT.

Q: WHAT IS AN EXAMPLE OF LIGHT BEHAVING AS A WAVE, NOT JUST A RAY?

A: DIFFRACTION, THE BENDING OF LIGHT AROUND SHARP EDGES OR THROUGH SMALL OPENINGS, IS A CLEAR DEMONSTRATION OF LIGHT'S WAVE NATURE. ANOTHER EXAMPLE IS INTERFERENCE, SEEN IN THE COLORFUL PATTERNS OF SOAP BUBBLES OR OIL SLICKS, WHERE LIGHT WAVES FROM DIFFERENT PARTS OF THE SURFACE INTERACT CONSTRUCTIVELY AND DESTRUCTIVELY.

Q: DOES CLASSICAL PHYSICS APPLY TO VERY LARGE OBJECTS LIKE PLANETS?

A: YES, CLASSICAL PHYSICS, PARTICULARLY NEWTONIAN MECHANICS, IS EXTREMELY SUCCESSFUL IN DESCRIBING THE MOTION OF PLANETS, STARS, AND GALAXIES. WHILE EINSTEIN'S THEORY OF GENERAL RELATIVITY OFFERS A MORE ACCURATE DESCRIPTION IN EXTREME GRAVITATIONAL FIELDS, CLASSICAL MECHANICS PROVIDES AN EXCELLENT APPROXIMATION FOR MOST ASTRONOMICAL CALCULATIONS.

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